Benchmark Study for Total Energy Deposition by High Energy Electrons in Thick Slabs

Insoo Jun
Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109-8099

Abstract

The total energy deposition profiles when high energy electrons impinge on a thick slab of elemental aluminum, copper, and tungsten have been computed using representative Monte Carlo codes (NOVICE, TIGER, MCNP), and compared in this paper.

Summary

The radiation transport analysis benchmark was performed to compare electron transport results from the NOVICE code (version 2000) with results from TIGER (1D module of ITS3.0) and MCNP version 4B.

The NOVICE code is fundamentally different from the other codes in the way the transport calculations are performed. NOVICE is an adjoint code specifically developed for space radiation transport applications whereas the other two codes are forward codes. Due to their widespread use in the radiation transport community, the forward codes have been benchmarked experimentally for electron transport problems. NOVICE, however, has not been experimentally benchmarked in a similar fashion, due to difficulties involved in producing a 4-pi omni-directional poly-energetic radiation source. The Jovian trapped radiation belts are populated with electrons with energies that are at least one order of magnitude more energetic than those found in the Earth's Van Allen belts. Figure 1 illustrates how severe the electron environment is at Jupiter as compared to a typical worst case geosynchronous earth orbit. At high energies, different physical processes, such as pair production and secondary electron production by bremsstrahlung photons, can become significant contributors to the total dose. The pair production and secondary electron physics are present in the forward codes, but are approximated in the NOVICE code. A new series of benchmarks are needed to ensure the NOVICE code can be used for a future Jovian mission where these effects may be important.

The main purpose of this paper is to compare the electron transport code used at JPL (NOVICE) with the other codes to gain a better understanding of its predictive capability for total energy deposition calculations in high energy (1-100 MeV) electron environment. ***In this study, the TIGER results were used as the baseline for the comparison because it has been successfully used on many occasions to reproduce experimental results [e.g. see Tabata et. al.]***

Problem Setup

In order to make the inter-comparison among the codes easier and to focus on the physics used in each code, only the semi-infinite slab geometry was considered in this study. This geometry is implicit in TIGER while thoughtful geometry modeling is necessary for MCNP and NOVICE because the latter two codes are 3D codes. In order to satisfy the semi-infinite assumption of the geometry, cylindrical slabs with height and radius of $10r_0$ and $100r_0$ were modeled for the MCNP and NOVICE calculations, where r_0 is the continuous slowing down approximation (CSDA) range of the incident electrons. The broad beam/mono-energetic source electrons were assumed to impinge on one side of the slab with a cosine distribution. The cosine source distribution was used because it is a built-in option in all three codes and easily convertible to an isotropic source problem. Then, the total doses were computed in the region up to $1.0r_0$ with $0.025r_0$ intervals. All the final results were normalized to the 1 electron/cm^2 source strength. The number of source particles simulated varies depending on the target material and source electron energy in order to achieve the statistical uncertainties of the results less than ~5% in the majority of the problem geometry.

Preliminary Results and Discussion

The results are presented in Figures 2 through 4 for aluminum, copper, and tungsten for 1, 10, and 100 MeV electron cases in terms of the ratios of the NOVICE or MCNPX results to the TIGER results. The results show that the agreement is good (<20%) between the TIGER and MCNP results. This was expected because the electron physics in MCNP4B is essentially the same as that implemented in TIGER, except for a few minor differences. For example, the small deviations at the deep regions, aside from the statistical uncertainties, can be attributed to the different bremsstrahlung physics adopted in the two codes. ***Detailed electron physics used in these codes will be discussed in the final paper.***

On the other hand, the NOVICE results are not that consistent with the TIGER results: (1) for 1 and 10 MeV electrons, NOVICE tends to underestimate the results for all three materials over the entire regions, and (2) for 100 MeV electrons, NOVICE overestimates the results up to 0.6-0.8 r/r_0 depth, and then underestimates the results in deeper regions. ***These behaviors of the NOVICE results are being investigated now and will be reported in the final paper.***

This finding led to further benchmarking study to investigate how the profiles would behave if actual electron spectrum (9.2 Rj Jovian spectrum in Figure 1) were used as an input to each code. The results are shown in Figure 5. The agreement among all 3 codes is excellent (<10% in most regions). It seems that underestimation and overestimation in NOVICE balance each other out to give closer agreement when using the actual spectrum, at least for the electron spectrum we used in this study. The results of this study provide confidence in NOVICE for electron transport analysis for future Jovian missions. However, the results of this study also emphasizes that NOVICE should be used with care, and may require a benchmarking studies similar to the one described in this paper for different electron source spectra.

Acknowledgment

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Selected References

J.A. Hableib et. al., "ITS 3.0: Integrated Tiger Series of Coupled Electron/Photon Monte Carlo Transport Codes," Radiation Safety Information Computational Center (RSICC), Code Package CCC-467, Oak Ridge National Laboratory, (1994)

J.F. Briesmeister, the Editor, "MCNP-4B: A General Monte Carlo N-Particle Transport Code, Version 4B," Los Alamos National Laboratory, Report Number LA-12625-M (1997)

T. Jordan, "NOVICE: Radiation Transport Shielding Code: 2000 version," Experimental and Mathematical Physics Consultants, Gaithersburg, MD (2000)

T. Tabata, P. Andreo, and R. Ito, "Energy-Deposition Distributions in Materials Irradiated by Plane-Parallel Electron Beams with Energies Between 0.1 and 100 MeV," Atomic Data and Nuclear Data Tables, Vol. 56, 105-131 (1994)

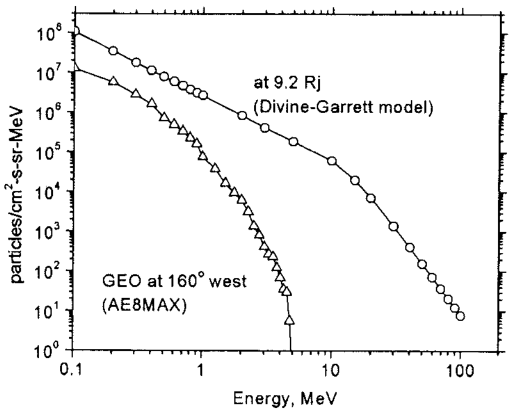

Figure 1. Electron differential spectra for typical GEO and Jovian environments computed based on AE8MAX and Divine-Garrett models, respectively.

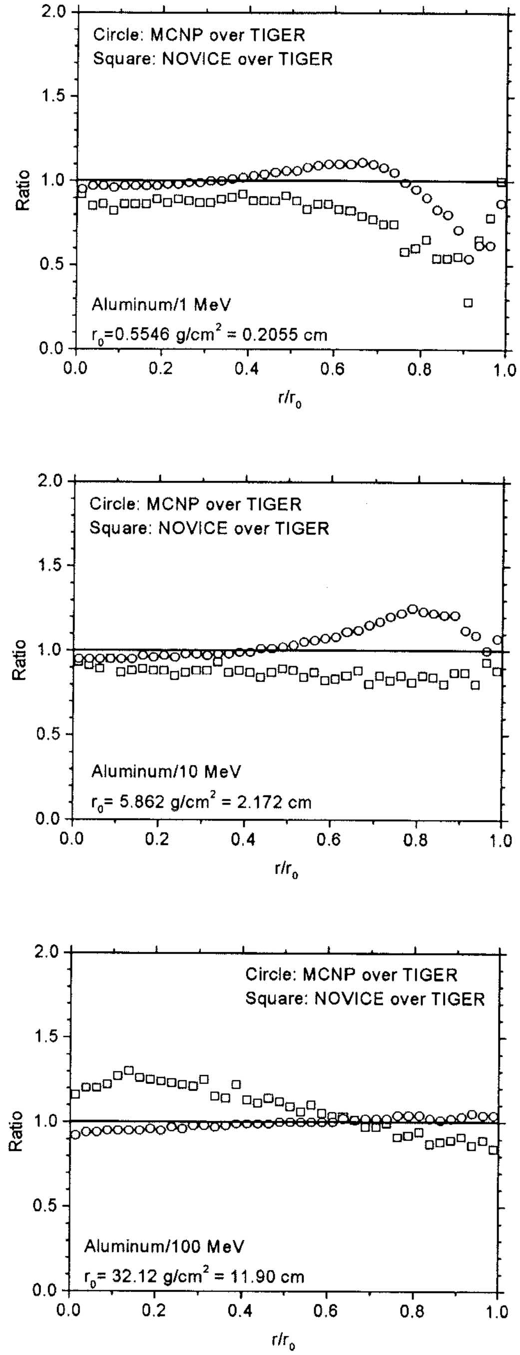

Figure 2. Total dose ratio profiles (NOVICE/TIGER and MCNP/TIGER) for aluminum target with mono-energetic 1, 10, or 100 MeV source electrons

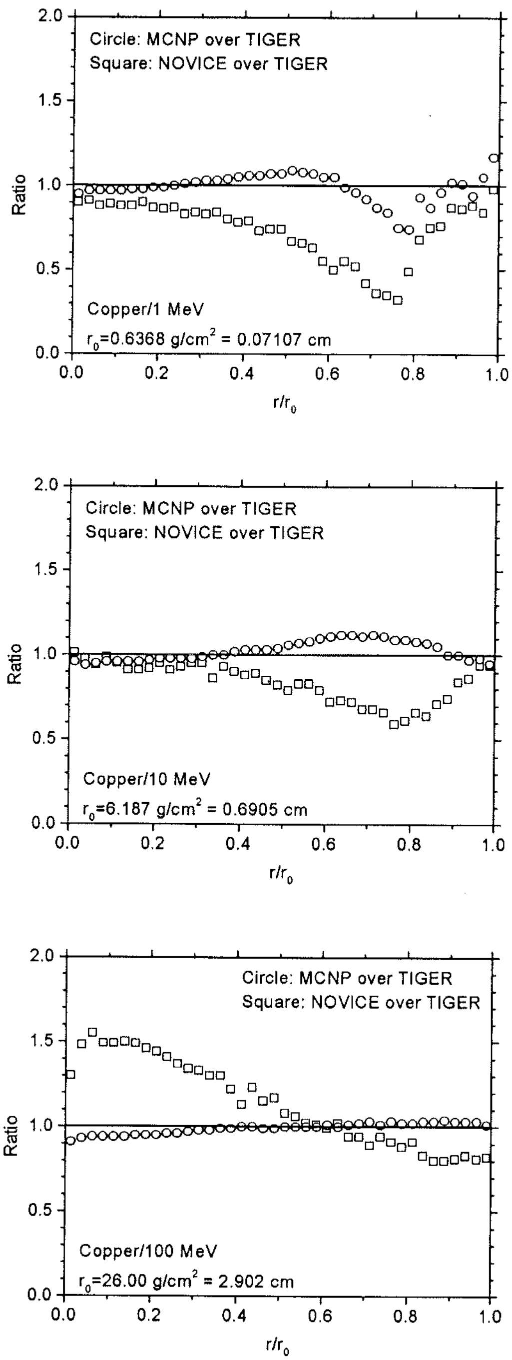

Figure 3. Total dose ratio profiles (NOVICE/TIGER and MCNP/TIGER) for copper target with mono-energetic 1, 10, or 100 MeV source electrons

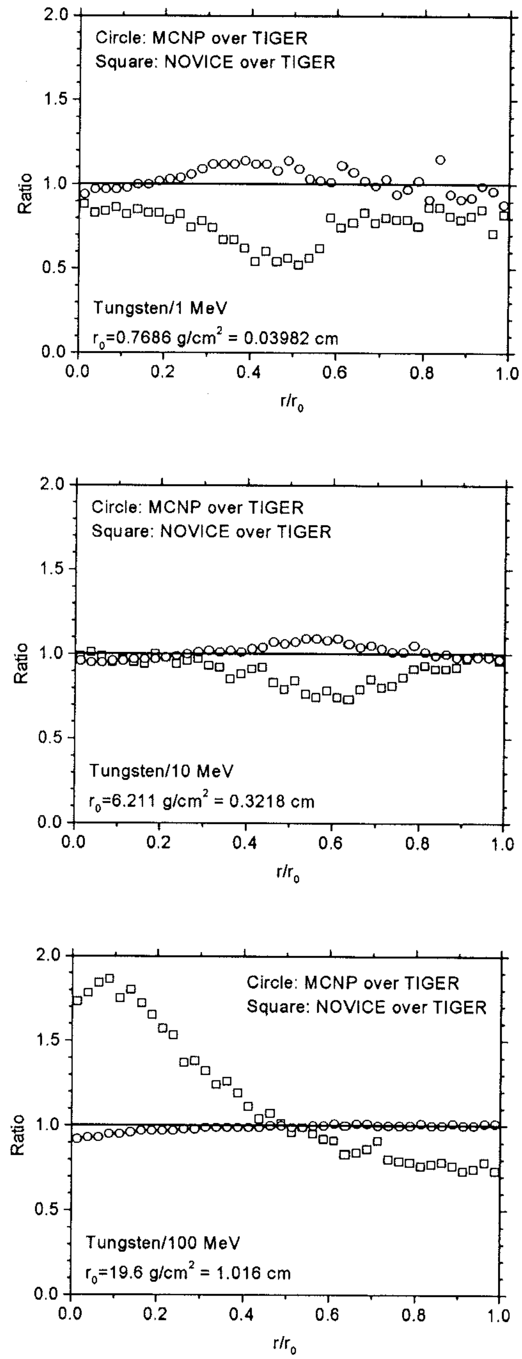

Figure 4. Total dose ratio profiles (NOVICE/TIGER and MCNP/TIGER) for tungsten target with mono-energetic 1, 10, or 100 MeV source electrons

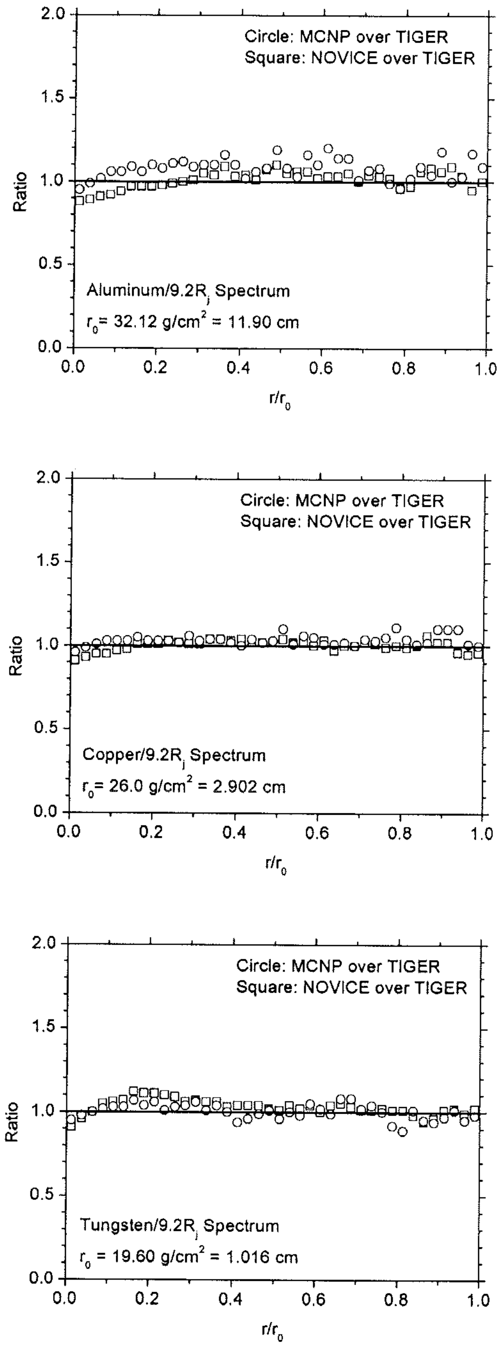

Figure 5. Total dose ratio profiles (NOVICE/TIGER and MCNP/TIGER) for aluminum, copper, and tungsten target with 9.2 Rj Jovian electron source spectrum